SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA
FACULTY OF MECHANICAL ENGINEERING

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MotoShield: Open Miniaturized DC Motor Hardware Prototype for Control Education

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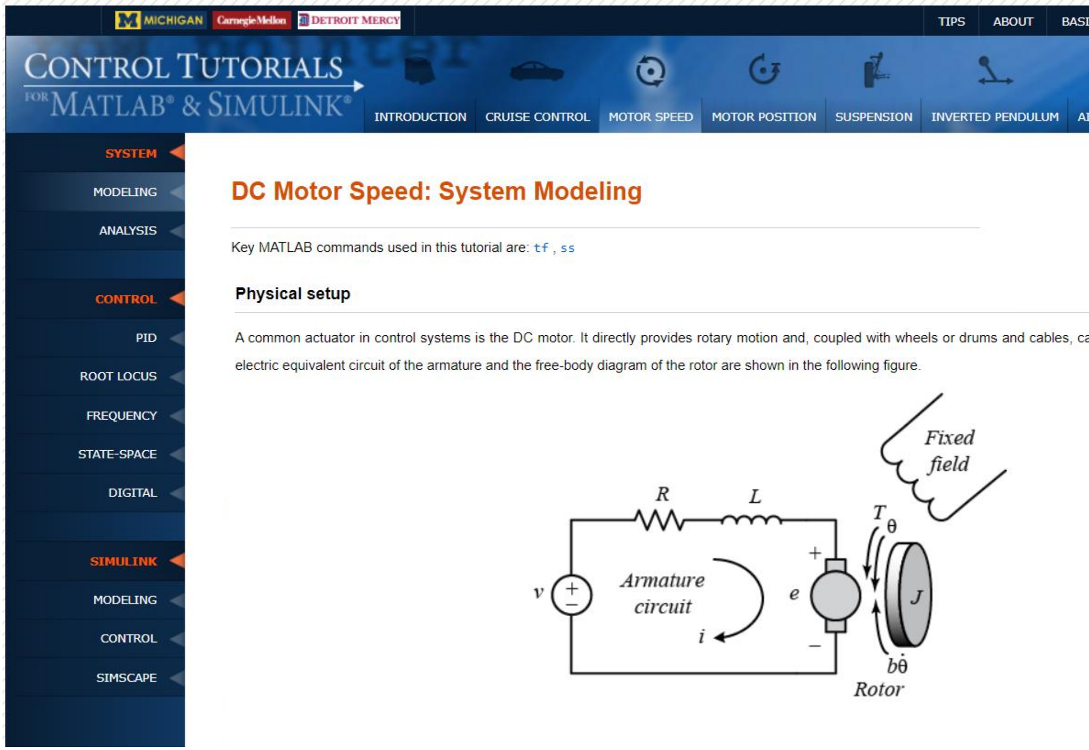
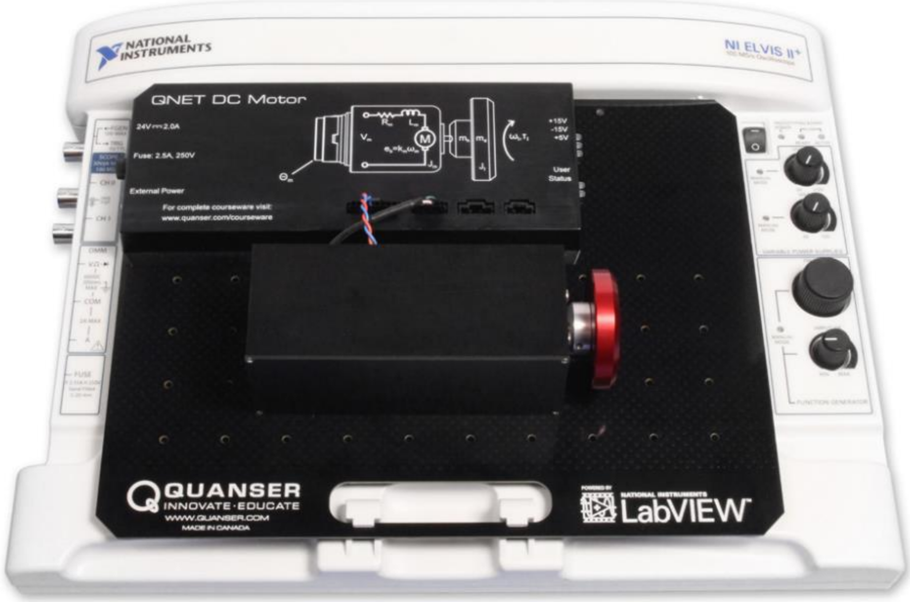
Motivation: Hands-on control engineering education

- Control engineering students require extensive hands-on training
- Numerical exercises and simulation examples are not enough
- The ongoing pandemic has shown the value of take-home experiments
- The closed-loop feedback control of the speed of a direct current (DC) motor is one of the fundamental examples in control engineering

DC Motor speed control simulation example in a well-known educational resource:



Motivation: DC motor control – Commercial Trainers

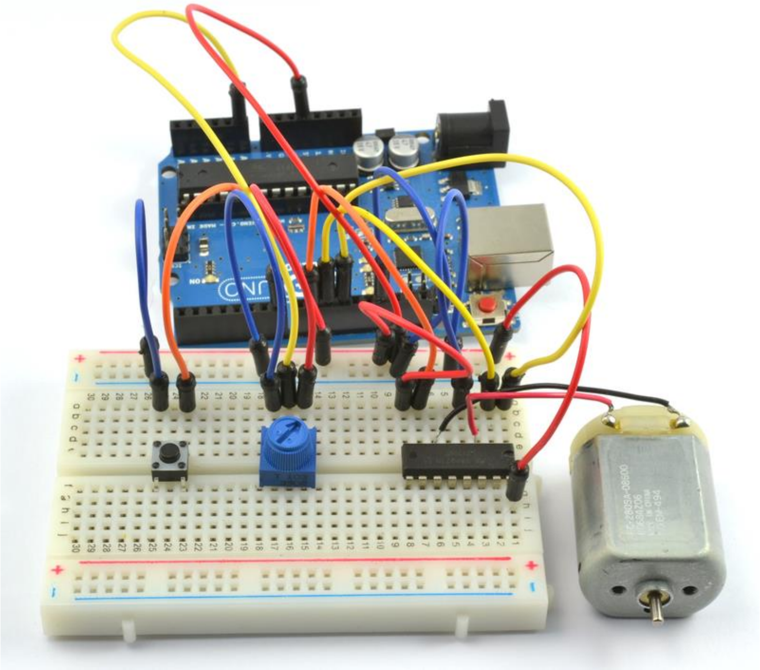


Quanser QNET DC Motor

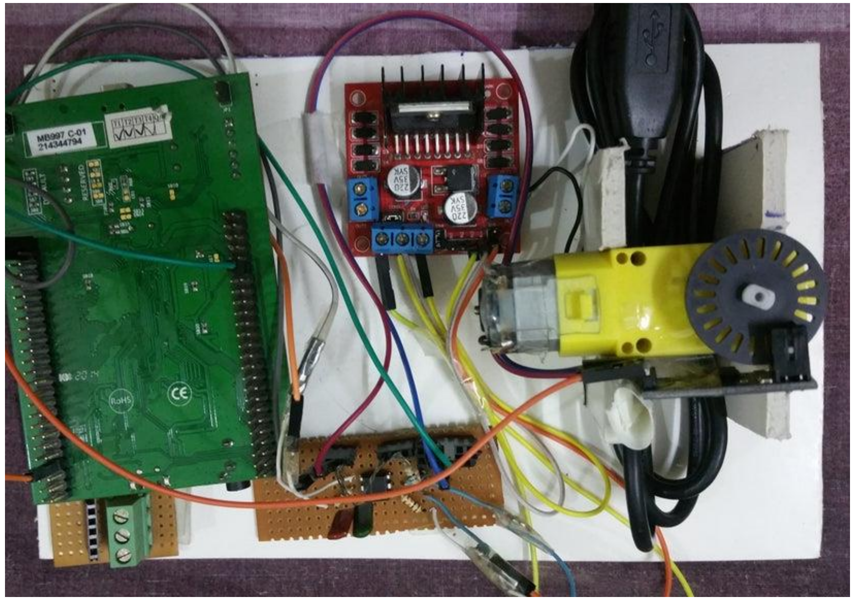
BYTRONIC DC Motor Training System

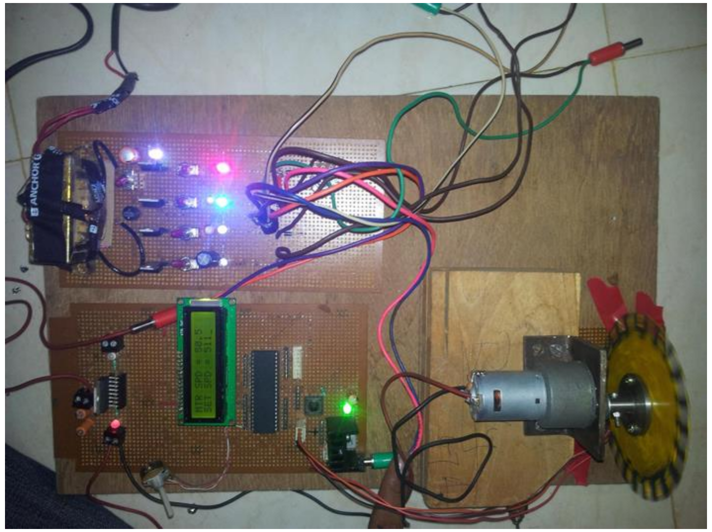
Xing Ke MMT1A

Motivation: DC motor control – Improvised Devices



Open-loop
(no feedback)!



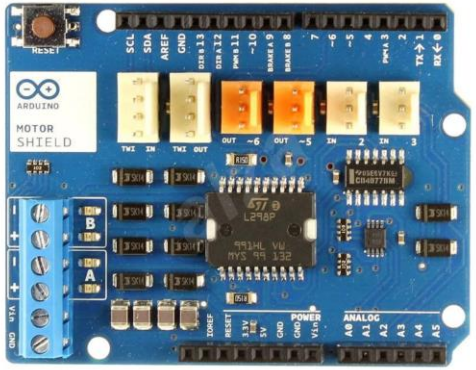


Motivation: Source of inspiration - Arduino, a universal platform to build on

- Cheap
- Open-source
- Easy to buy
- Standardized
- Free integrated development environment (IDE)
- Great community and abundance of learning materials
- **Cross-compatibility and easy hardware expansion through so-called Shields**

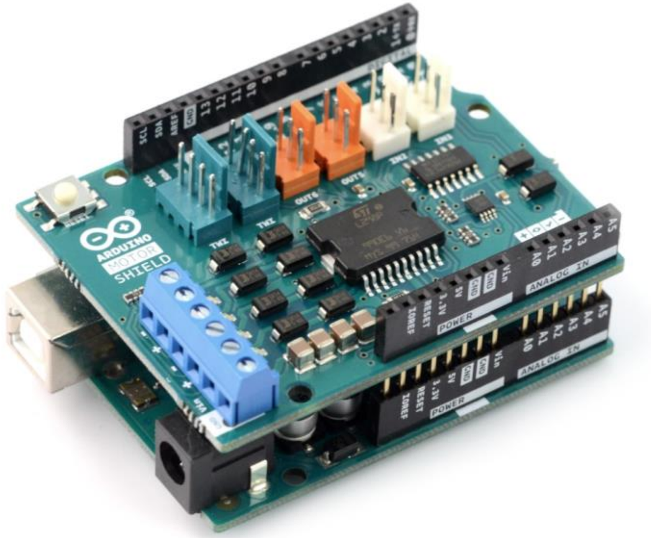
Arduino

+



Shield (e.g. Motor control)

=



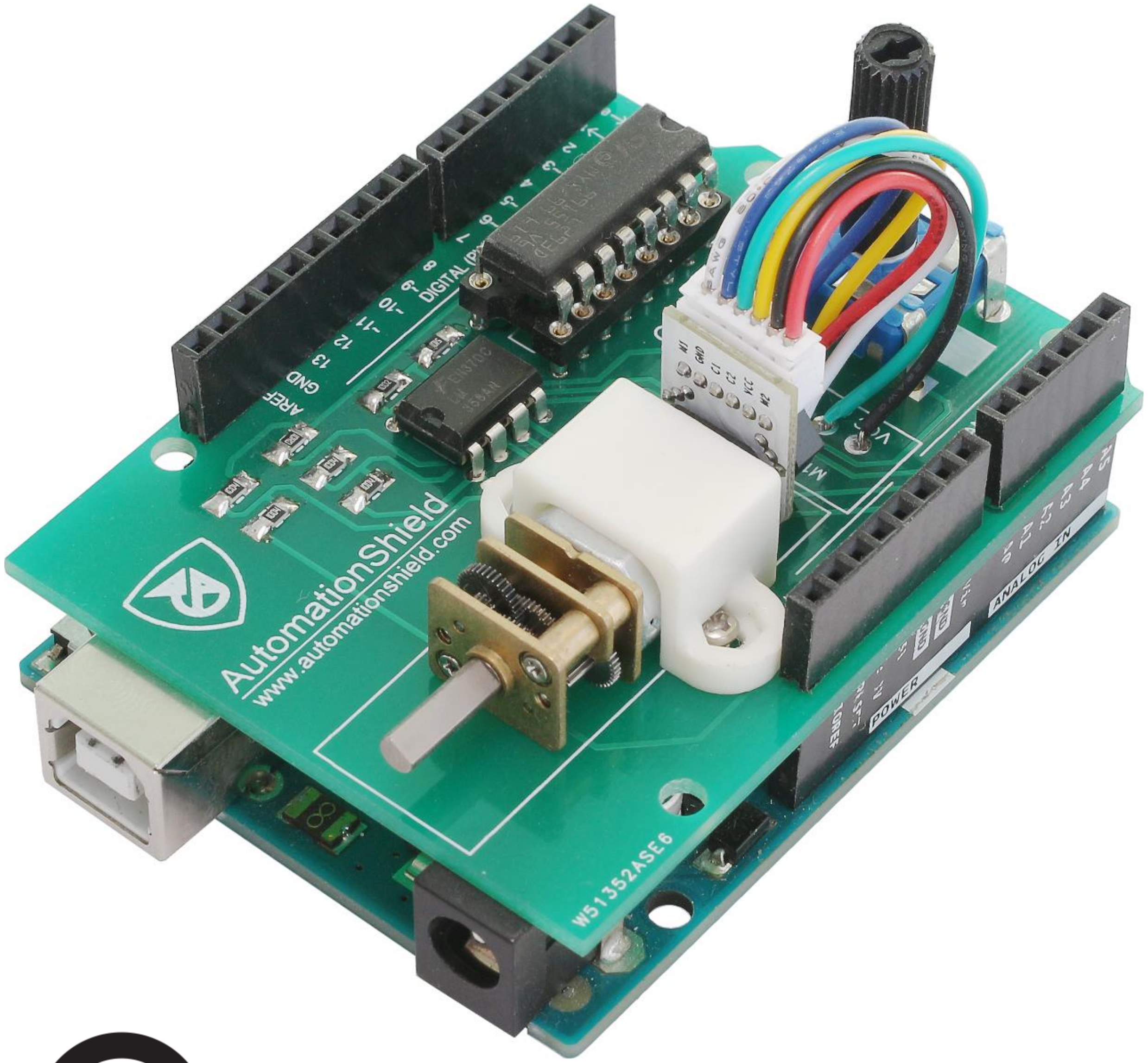
AutomationShield
Control Engineering Education

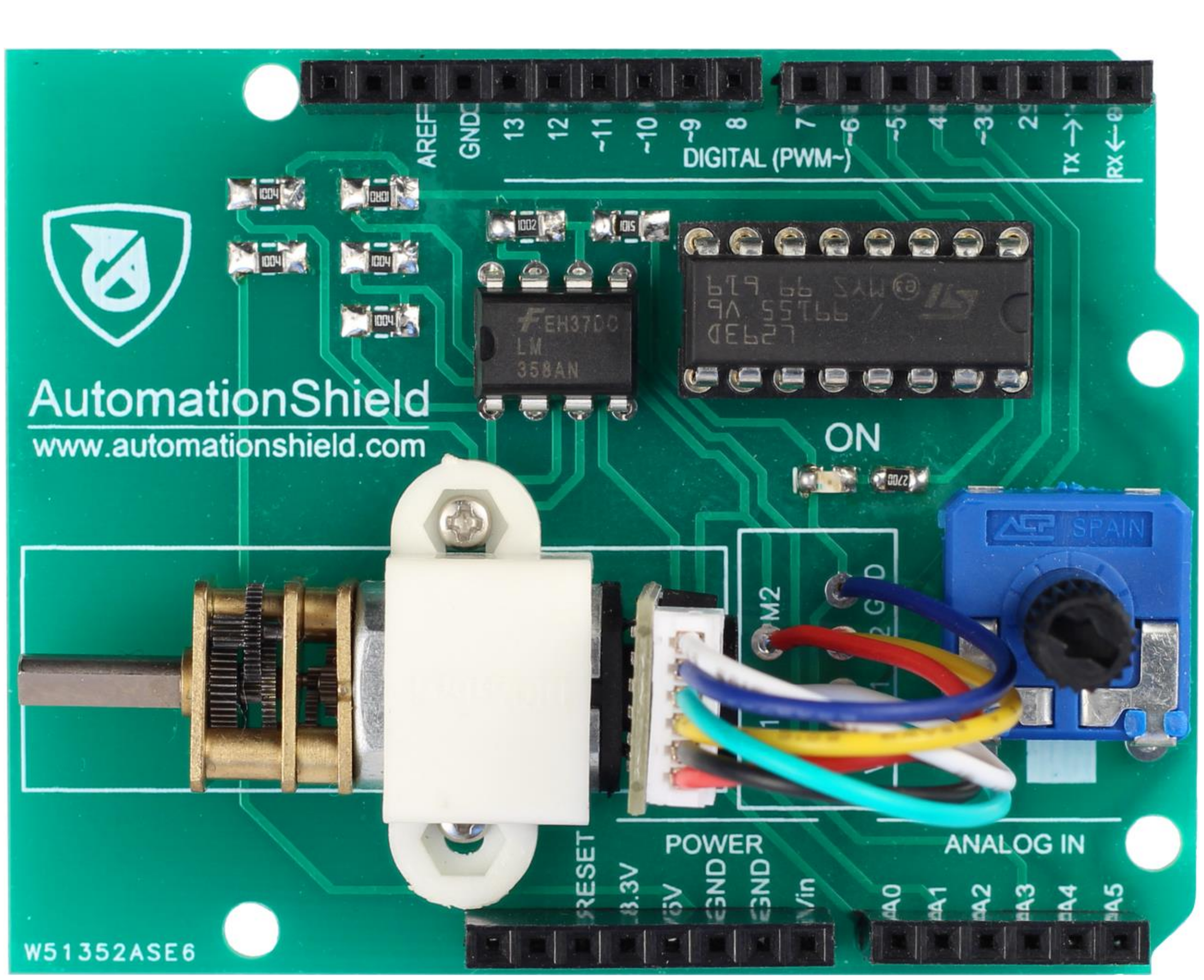
Create novel tools for control engineering and mechatronics education, implementing a lab experiment on a single Arduino expansion Shield, essentially a tiny control / mechatronics laboratory in the palm of your hand that is

- Cheap
- Open-source
- Possible to build at home even by beginners (DIY)
- Standardized
- Free software library compatible to the Arduino IDE

Visit www.automationshield.com …

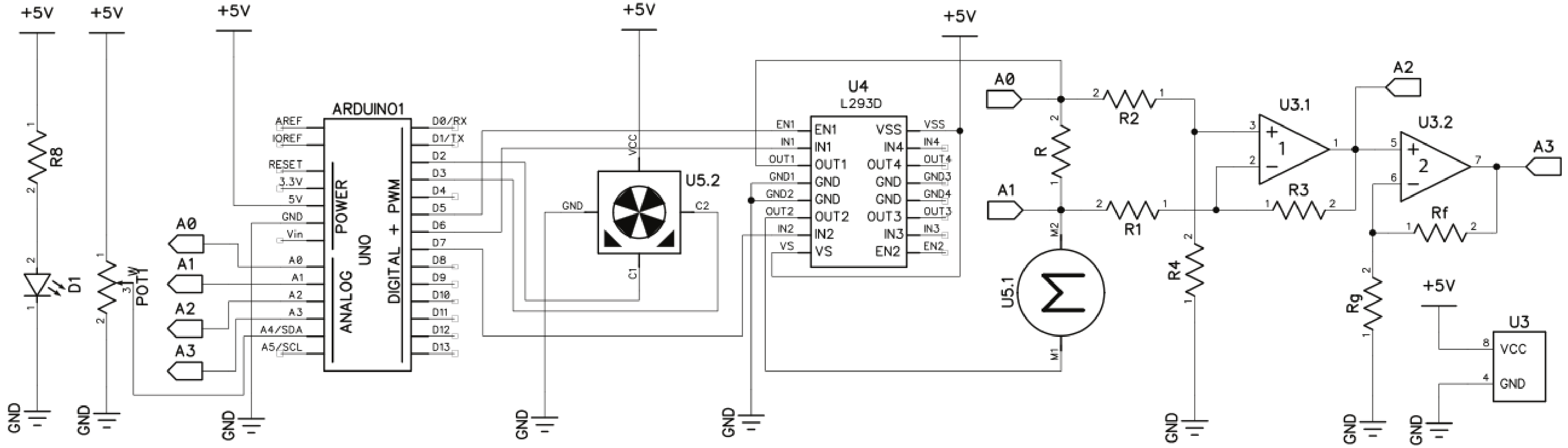
Introducing the **MotoShield** – an early prototype



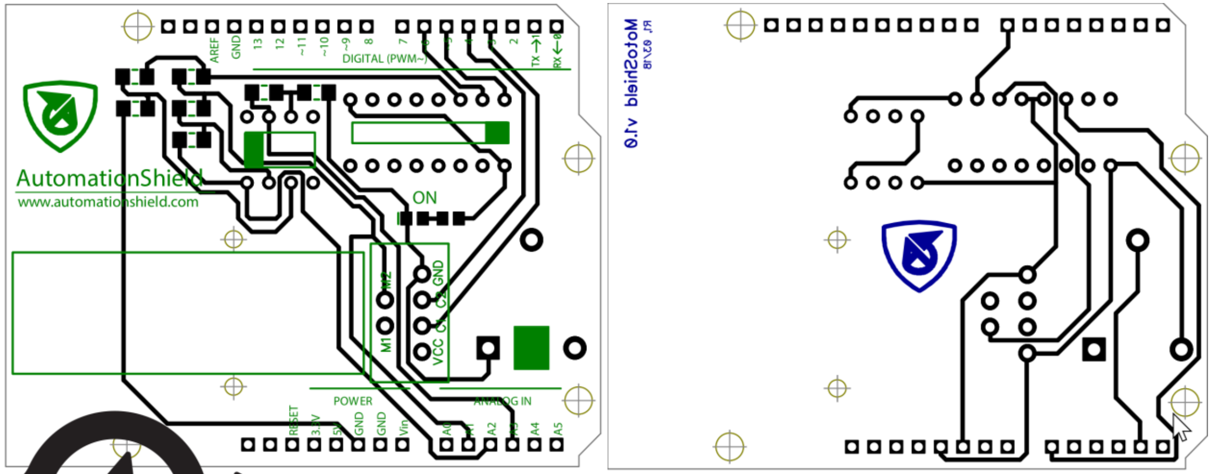


MotoShield: Open-Source Hardware (see www.automationshield.com)

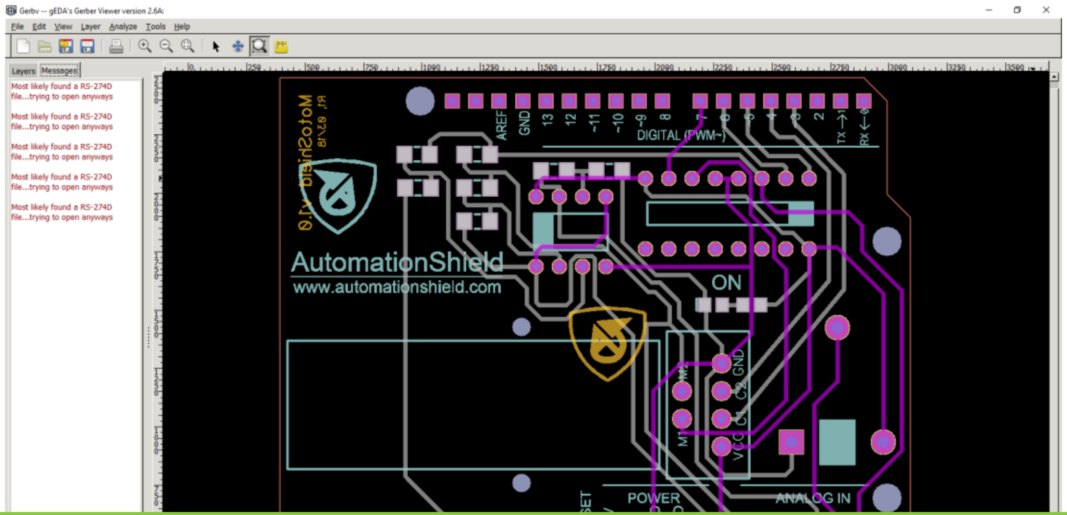
Editable schematic files:



Editable PCB layouts:



Manufacturing-ready formats:



MotoShield: A truly low-cost hardware

Name	Description	PCB	Mark	Pcs.	Unit	Total ($)
PCB	FR4, 2 layer, 1.6 mm thick		(a)	1	0.48	0.48
DC motor	DFRobot FIT0487 DC motor with gearbox and encoder	U5	(c)	1	12.20	12.20
Motor bracket	DFRobot FIT0160 plastic bracket for motor with bolts and nuts		(d)	1	3.68	3.68
Opamp	LM358AN, operational amplifier	U3	(g)	1	0.24	0.24
Motor Driver	L293D, push-pull 4-channel motor driver	U4	(e)	1	3.59	3.59
DIP16 socket	DIP16 IC socket	U4		1	0.08	0.08
Resistor	1 MΩ 0.5%, 0805, SMD	R1,R2,R3,R4	(h)	4	0.03	0.12
Resistor	10 Ω 0.1%, 0805, SMD	R	(f)	1	0.03	0.03
Resistor	10 kΩ 0.5%, 0805, SMD	Rf	(i)	1	0.04	0.04
Resistor	5.1 kΩ 0.5%, 0805, SMD	Rg	(j)	1	0.016	0.016
Resistor	270 Ω 5%, 0805, SMD	R8	(m)	1	0.004	0.004
LED	Red LED, 0805, SMD	D1	(n)	1	0.07	0.07
Pot shaft	5×18.7 mm; e.g. ACP 14187-NE		(l)	1	0.10	0.10
Trimmer	10 kΩ , 250 mW, single turn THT trimmer	POT1	(k)	1	0.34	0.34
Header	10×1, female, stackable, 0.1" pitch (e.g. SparkFun 474-PRT-10007)		(b)	1	0.072	0.072
Header	8×1, female, stackable, 0.1" pitch (e.g. SparkFun 474-PRT-10007)		(b)	2	0.22	0.22
Header	6×1, female, stackable, 0.1" pitch (e.g. SparkFun 474-PRT-10007)		(b)	1	0.11	0.11

$22

MotoShield: Arduino API

Simplified application programming interface (API) in C/C++ included within the **AutomationShield library** for the free Arduino IDE:

- Initialize hardware
```
MotoShield.begin();
```
- Calibrate speed limits
```
MotoShield.calibration();
```
- Read motor speed to *y* (% or rpm)
```
y = MotoShield.sensorRead();
```
- Send a certain power *u* to DC motor (% PWM)
```
MotoShield.actuatorWrite(u);
```
- Read external reference *r*
```
r = MotoShield.referenceRead();
```

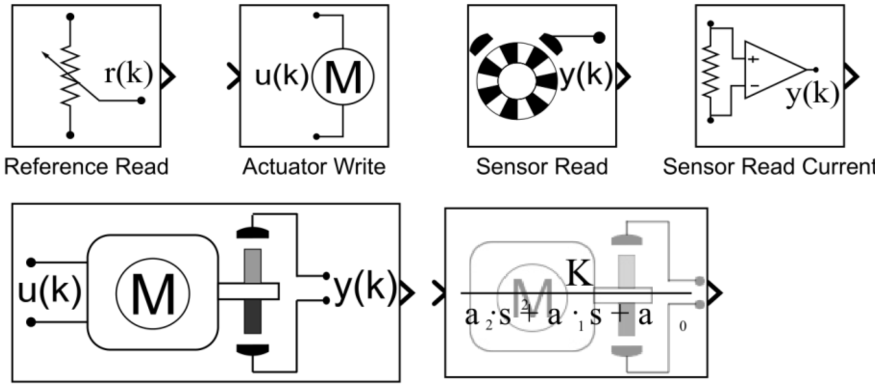
MotoShield: Further possibilities: MATLAB and Simulink API

API available for MATLAB as well, keeps consistent nomenclature and usage with the Arduino API:

- Initialize hardware
  `MotoShield.begin()`
- Calibrate speed limits
  `MotoShield.calibration()`

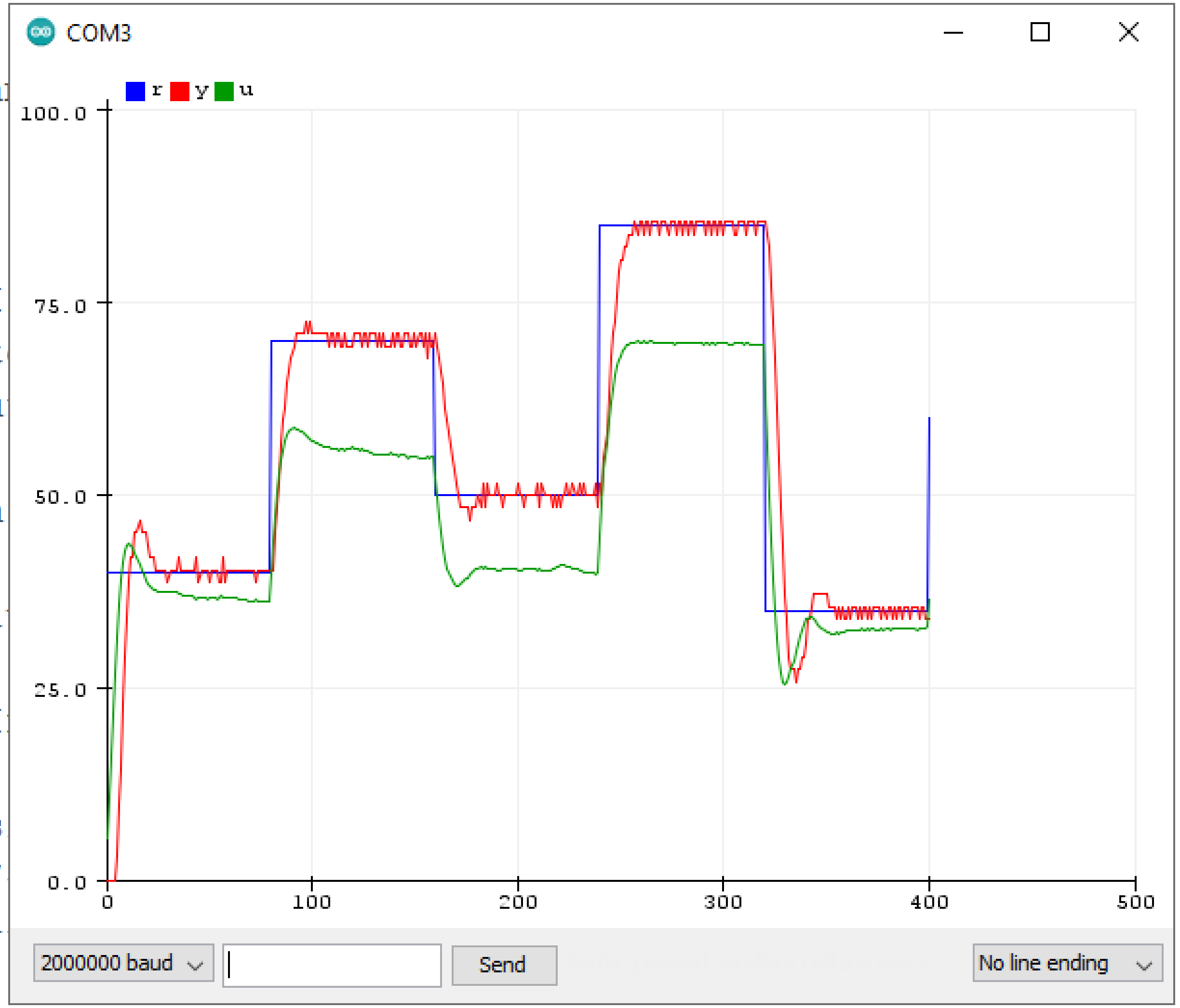
[...]

API created for the Simulink with real-time control and deployment features:



Typical classroom examples: PID control (Arduino IDE)

```
    MotoShield.stepEnable=false;  //--Setting the flag to false # built-in ISR sets flag to true at the e
  }
}
void step(){ //--Algorith ran once per sa
#if !AUTO
  r = MotoShield.referenceRead();
#else AUTO
  if(i >= sizeof(R)/sizeof(float)){ //--I
    MotoShield.actuatorWrite(0.0); //--St
    while(true); //--End of program execu
  }
  if (k % (T*i) == 0){ //--Moving through
   r = R[i];
    i++;               //--Change input val
  }
  k++;                                //--I
#endif
y = MotoShield.sensorRead();       //--Sens
u = PIDAbs.compute(r-y,0,100,0,100);    //
MotoShield.actuatorWrite(u);           //-
```



Typical classroom examples: System Identification (MATLAB)

MATLAB

1. First-principles modeling

$$
\begin{aligned}
J\ddot{\omega}(t) &= K_t i(t) - b\dot{\omega}(t) \\
U(t) &= Ri(t) + L\frac{\mathrm{d}i(t)}{\mathrm{d}t} + \varepsilon(t),
\end{aligned}
$$

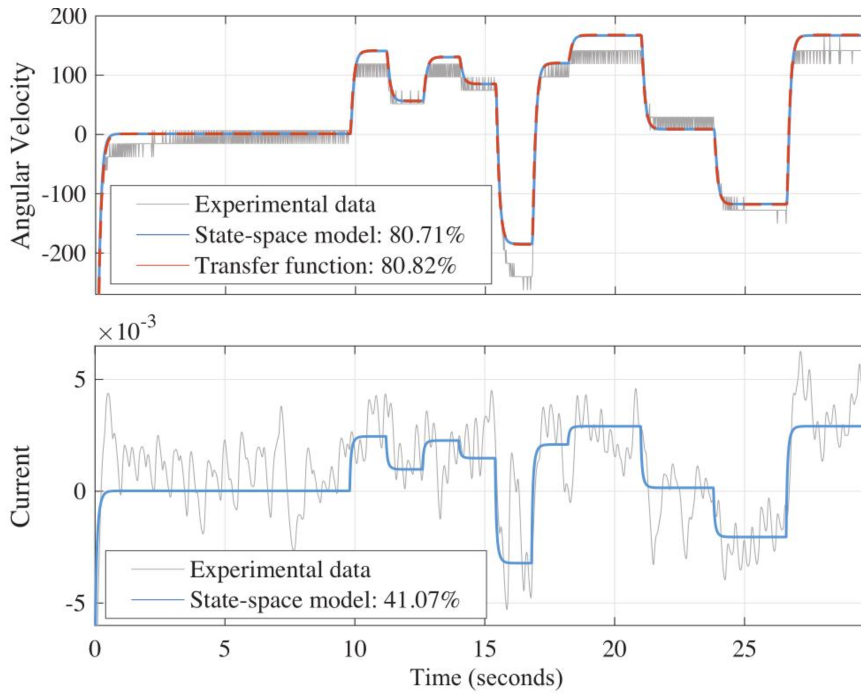
$$G(s) = \frac{K}{K^2 + (Js+b)(Ls+R)}$$

$$\begin{bmatrix} \ddot{\omega}(t) \\ \dot{i}(t) \end{bmatrix} = \begin{bmatrix} -\frac{b}{J} & \frac{K}{J} \\ -\frac{K}{L} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} \dot{\omega}(t) \\ i(t) \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{L} \end{bmatrix} U(t)$$

2. DAQ and Identification

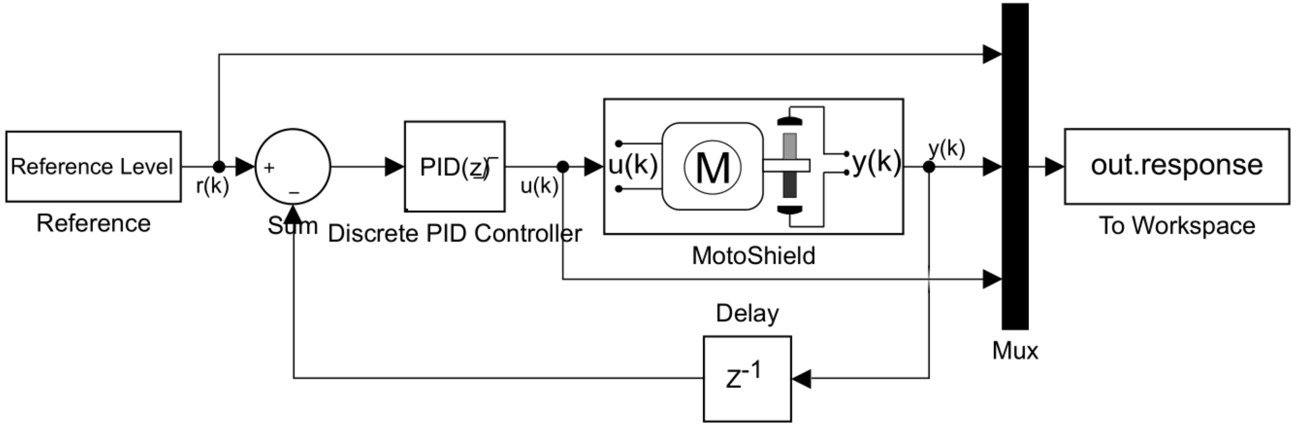
```
data = detrend(data);
data.InputName = 'Input Voltage';
data.InputUnit =  'V';
data.OutputName{1} = 'Angular Velocity';
data.OutputUnit{1} = 'rad/s';
data.OutputName{2} = 'Current';                %_
data.OutputUnit{2} = 'A';
data.Tstart = 0;
data.TimeUnit = 's';

%% Initial guess of model parameters
J = 0.01;          %_Moment of inertia
b = 0.1;           %_Viscous friction constant
Ke = 1;       %_Electromotive force constant # Vo
Kt = 1;       %_Motor torque constant # Torque ov
R = 10;            %_Electric resistance
L = 3;           %_Electric inductance

dtheta0  = data.y(1,1);         %_Initial veloci
i0 = data.y(1,2);         %_Initial current

    %_StateSpace Model
    A = [-b/J      Kt/J;
         -Kt/L     -R/L];

    B = [ 0;
        1/L];

    C = [1 0;
         0 1];
    D = [0;
         0];
    K = zeros(2,2);
    x0 = [dtheta0; i0];
```

3. Validation

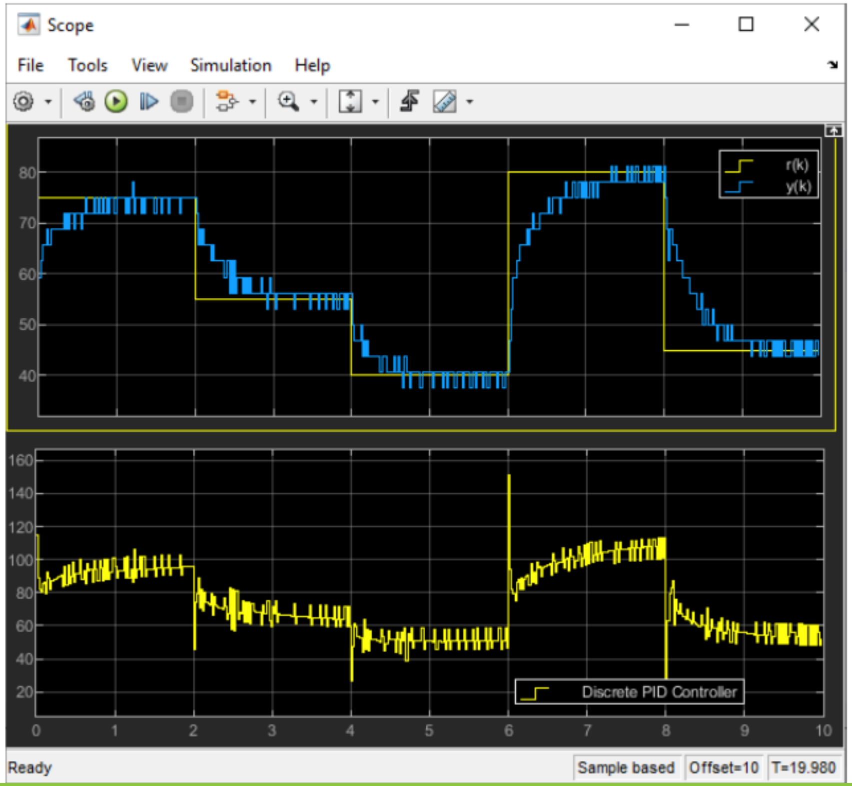


Typical classroom examples: Auto-generated control code (Simulink)

1. Block scheme using the Simulink API

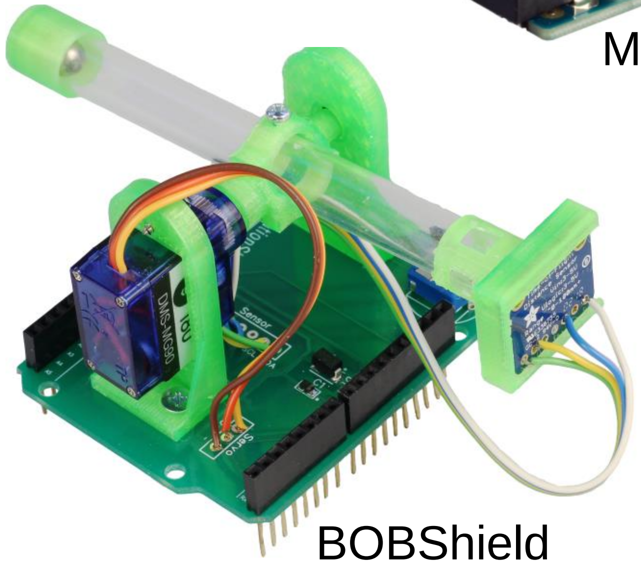


2. Deployment to MCU and live view



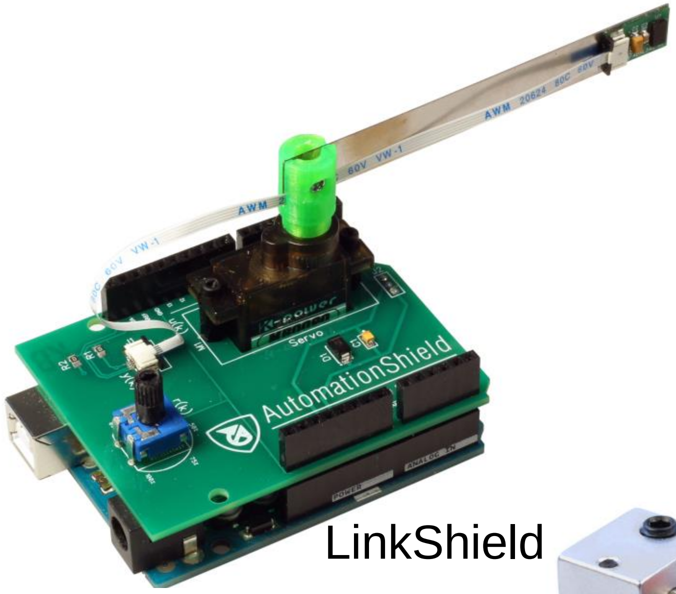
Other “shields” within our open initiative – visit www.automationshield.com

FloatShield



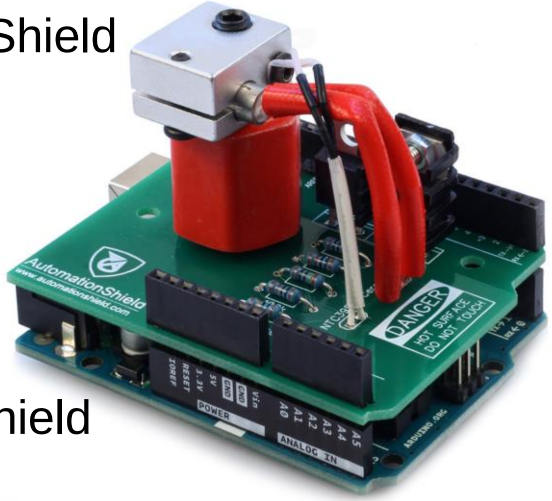
BOBShield

MagnetoShield



LinkShield

OptoShield



HeatShield

AutomationShield

Control Systems Engineering Education

Thank you for your attention!

Visit www.automationshield.com for more details

and please feel free to contact me any time via:

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e-mail: gergely.takacs@stuba.sk

researchgate.net/profile/Gergely_Takacs

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